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APPLICATION FOR LETTERS PATENT

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METHODS OF INCREASING POWER HANDLING
CAPABILITY OF A POWER LINE

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INVENTOR

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1 **METHODS OF INCREASING POWER HANDLING CAPABILITY OF**
2 **A POWER LINE**

3 **CROSS REFERENCE TO RELATED APPLICATIONS**

4 This application claims priority from U.S. Provisional application
5 60/036,021, filed January 31, 1997, titled "Nip and Tuck Power Line
6 Rerating Process", and incorporated herein by reference.

7
8 **TECHNICAL FIELD**

9 This invention relates to electrical power line re-rating of overhead
10 conductors using one or more of two possible modifications not
11 previously used for this purpose: removing small lengths of conductor,
12 and repositioning conductor support clamps. More particularly, this is
13 a process of determining and making the least cost adjustments to the
14 conductor system of a particular, existing overhead electrical power line
15 so as to allow the conductors in that line to operate at a higher
16 temperature than currently rated without violating safety codes, safety
17 clearances or design standards criteria for conductor sag and tension
18 using these possible modifications, separately or in combination with
19 each other. The intent of these modifications is to selectively increase
20 the tension in the conductor so as to eliminate clearance violations
21 caused by an increase in the sag of the conductor resulting from an
22 increase in the power transfer capability of the electrical power line.

1 BACKGROUND OF THE INVENTION

2 Electrical power line owners have a desire and need to transmit
3 more power over existing power lines. As the amount of power being
4 transmitted over a given line (conductor) increases, the temperature of
5 the conductor increases. As the temperature of the conductor increases,
6 the sag of the conductor increases. Existing weather conditions,
7 conductor installation conditions and structural characteristics of the line
8 also affect the amount of sag. Excess sag can put the conductor so
9 close to objects on the earth as to cause flashover, which can damage
10 the line and nearby facilities, cause power outages and endanger animal
11 and plant life.

12 The current method for line re-rating is to combine sag and
13 tension calculations with any one of a number of commercially available
14 power line analysis computer programs, including longitudinal loading
15 models, to calculate the maximum amperage or conductor temperature
16 that can be used for that line which will not violate safety codes or
17 clearance criteria, nor cause structural or conductor damage. If the
18 desired or required conductor temperature cannot be achieved with the
19 existing design, then the power line owner must resort to one or more
20 of the standard current methods of eliminating the clearance violations.
21 These standard methods include: re-conductoring, raising existing
22 structures, re-tensioning the line between dead end sections, or inserting
23 additional structures. The re-rating process may or may not include
24 field verification of the physical parameters of the power line.

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1 Inherent in any power line rating or re-rating process is the need
2 to determine the behavior of the whole power line and individual
3 conductors operating at higher temperatures. The behavior (sag) of the
4 conductors at high temperatures is generally determined by computer
5 programs, such as Alcoa's SAG10, that calculate the tension and
6 corresponding sag of the conductor based on input of environmental
7 parameters, conductor creep, temperature ranges and other factors.
8 SAG10 is generally available and commonly used within the industry.

9 The behavior of the power line at high temperatures is
10 determined by a longitudinal loading model. Longitudinal loading
11 models calculate the position of the wire after a change in temperature
12 or loading has occurred. The calculations in these models are based
13 upon the length of wire in a span being fixed at a point in time with
14 known environmental conditions (e.g., ambient temperature) and known
15 geometry and physical characteristics (e.g., longitudinal movement of the
16 conductor supports (insulators), type of conductor support, flexibility of
17 the structures, relative elevation of conductor supports and the spans
18 between structures). As the temperature or loading of the wire
19 changes, the length of wire in that span changes based upon the
20 geometry of the span and the physical properties of the wire, such as
21 coefficient of thermal expansion and creep.

22 Presently, several procedures exist, used individually or in
23 combination, to predict how much power can be transmitted over an
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1 existing power line, under given environmental conditions, without
2 violating safety codes or design standards.

- 3 1. The Institute of Electrical and Electronics Engineers (IEEE),
4 Electrical Power Research Institute (EPRI) and Power
5 Technologies Inc. (PTI) and others, have developed and modified
6 computer programs which calculate the electrical capacity (rating)
7 of a power line based upon thermodynamics and heat transfer
8 physics. These programs use environmental parameters, such as
9 wind speed, wind direction, ambient temperature, solar radiation
10 and line direction to calculate allowable amperage of a line.
11 "Worst case" environmental parameters are established and the
12 power line rating is calculated. These programs, used in
13 combination with a longitudinal load model or power line analysis
14 program establish the maximum amperage (or conductor
15 temperature) at which the line can be operated without violating
16 clearance criteria or damaging the conductor(s). Exceeding this
17 upper bound will very likely cause clearance violations, damage
18 the conductor, or both. The mathematical formulas found in the
19 power line rating programs are generally accepted within the
20 industry.
- 21 2. Devices can be installed on the line to monitor the tension in
22 the conductor. Conductor tension is combined with other
23 environmental data, such as the ambient temperature and solar
24 radiation, to predict the rating or electrical capacity of the line.

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Patent Nos. 5,517,864 and 5,235,861, both by Tapani O. Seppa (and other patents noted therein), relate to methods of calculating the approximate actual sag of an overhead power transmission line by measuring the amount of tension on the line either by tensiometers or swing angle indicators, as well as measuring ambient temperature, both done at two different times, with no power flow, and then remotely transmitting that information to a computer for performance of calculations. From the data received, a Ruling Span can be calculated from which to determine a maximum safe current that can be transmitted by the existing line without creating excess conductor sag.

3. Israel Electric Company, Haifa, Israel has occasionally used selected algorithms to approximate actual sag under certain combinations of conditions of weather, power transmission and physical design; using basic longitudinal load modeling techniques.
4. Power Line Systems, Inc. is understood to have a computer program (SagSec Software by Peyrot of Power Line Systems, Inc. of Madison, WI) that performs a mathematical analysis of sag and tension, using longitudinal load modeling, including allowance for longitudinal insulator movement.
5. Multiple power line analysis, pole/tower spotting optimization, profile analysis and display computer programs exist, including TLCADD™, PLSCADD, and Optimal. These computer programs

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1 are primarily used in the power line rating process to calculate
2 clearance to the conductors.

- 3 6. Current methods to increase the amount of power transmitted
4 over a given line generally require taking the line out of service
5 to make extensive modifications to the conductors or structures,
6 or both. An existing conductor can be replaced with a larger
7 conductor to allow the electrical line to carry an increased load.
8 Alternatively, structures in the existing line can be raised or
9 replaced to allow for the increased sag of the existing conductor
10 when carrying the higher electrical load. Also, new structures can
11 be installed between existing structures to eliminate the low
12 clearance areas caused by increased conductor sag.

13 The procedures of removing small lengths of conductor and of
14 sliding support clamps have been used in other contexts, but have not
15 been considered for the purpose of re-rating of power lines, as analysis
16 tools and procedures have not been available to perform the complex
17 calculations needed to determine where to make such removals or slide
18 such clamps.

1 **BRIEF DESCRIPTION OF THE DRAWINGS**

2 Preferred embodiments of the invention are described below with
3 reference to the following accompanying drawings.

4 Figs. 1, 1A are a logical flow chart of the re-rating process.

5 Fig. 2 is a graph illustrating how Figs. 2A-2C are assembled.

6 Figs. 2A-2C are a sample of the computer written output showing
7 where along the line a portion of a conductor should be removed, and
8 how much and in which direction to slip the support clamps.

9 Fig. 3 is a sample of the computer graphic output showing the
10 sag of the conductor under various conditions analyzed.

11
12 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

13 This disclosure of the invention is submitted in furtherance of the
14 constitutional purposes of the U.S. Patent Laws "to promote the
15 progress of science and useful arts" (Article 1, Section 8).

16 A portion of the disclosure of this patent document contains
17 material which is subject to copyright protection. The copyright owner
18 has no objection to the facsimile reproduction by anyone of the patent
19 document or the patent disclosure, as it appears in the Patent and
20 Trademark Office patent file or records, but otherwise reserves all
21 copyright rights whatsoever.

22 The purpose of this invention is to analyze, redesign and field
23 modify an existing electrical power line such that it will be able to
24 carry more power without violating clearance criteria, and without

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1 necessarily having to change out the conductor, alter the structures or
2 de-energize the line (where energized line work is permissible and
3 economically advantageous), using the following two procedures,
4 separately or in combination with each other, to eliminate the clearance
5 violation:

- 6 1. Removing a length of conductor in the span with the clearance
7 violation, or in adjacent spans;
- 8 2. Adjusting the conductor support clamps on structure(s) adjacent
9 to or in the vicinity of the clearance violation.

10
11 In particular, this process includes:

- 12 1. A determination of whether removal of a portion of the conductor
13 is possible, and if so, how much and where to make such
14 removals;
 - 15 2. A determination of whether adjusting the conductor support
16 clamps is possible, and if so, where and how much to move the
17 support clamps;
 - 18 3. Estimations of the costs of making these adjustments and
19 modifications, as well as the costs of using standard procedures
20 now in practice;
 - 21 4. A recommendation of the best combination of conductor
22 temperature, modification procedure and associated costs; and
23 5. Performing the actual modifications recommended.
- 24

1 Data is gathered (Fig. 1: Items 1, 2, and 3) from original design
2 documentation and drawings, industry standards and field records. This
3 data includes:

- 4 1. (Fig. 1:1) Meteorological conditions to be considered,
5 especially: temperature ranges; wind velocities and directions;
6 and anticipated ice loadings;
- 7 2. (Fig. 1:1) Clearance requirements, especially: above ground
8 (Fig. 3:1); from edge of right-of-way; over special areas
9 such as railroads, roadways, and fences;
- 10 3. (Fig. 1:1) Cost elements, especially: labor; construction
11 equipment; structures and parts thereof; conductors;
12 insulators; time to do certain types of tasks associated with
13 re-rating lines; opportunity costs if the line must be de-
14 energized to make alterations;
- 15 4. (Fig. 1:1) Conductor characteristics, especially: size; tensile
16 strength; creep and stress characteristics over time and at
17 various temperatures, including field measured unbalanced
18 tensions; types and sizes of clamps needed;
- 19 5. (Fig. 1:3) Structure characteristics, especially: spacing
20 between (Fig. 3:2); distances from edges of right-of-way;
21 heights; weight bearing capacities (Fig. 3:4); flexibility (Fig.
22 3:4); insulator type, dimensions, length, swing, strength and
23 field measured actual positions (Fig. 3:4); dead-end locations;
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1 angle locations and actual line angles; attachment heights
2 (Fig. 3:3);

- 3 6. Terrain over which the line passes, especially: elevation (Fig.
4 3:5); width of right-of-way; and special features.

5
6 Profile drawings are scanned and digitized using commercially
7 available drafting programs (Fig. 1:4).

8 All of the data collected is loaded into complete, formatted
9 databases for use in, and as required by, commercially available
10 engineering profile analysis and display programs, such as TLCADD (Fig.
11 1:5). This data is used for the following calculations.

12 From the data collected, and using a longitudinal loading model,
13 a preliminary analysis of the power line is performed to evaluate the
14 quality of data collected and identify the problem spans (Fig. 1:5A).
15 Based upon the preliminary evaluation, a detailed visual inspection and
16 detailed survey may be undertaken (Fig. 1:3) to improve the quality of
17 the input data and analysis.

18 Structural analysis is made of all structures to determine maximum
19 strength and flexibility, using standard, commercially available structural
20 analysis programs, such as STAAD-III, by Research Engineers, Inc.

21 Conductors are analyzed to determine maximum available strength,
22 sag and creep characteristics, using standard, commercially available
23 conductor sag and tension analysis programs, such as Alcoa's "SAG10".
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1 A best fit, or "Base Case", computer model of the line is
2 developed to accommodate all the existing data of the line section.
3 This includes plan and profile data, adjusted by field surveys of spans,
4 sags, significant insulator offsets and pole deflections all at the base
5 case temperature.

6 A "Trial A" is then calculated using a longitudinal loading model
7 analysis (Fig. 1:6). This base case shows what would happen to the
8 conductors if operated at the maximum desired operating temperatures
9 without modification. The multiple-iteration analysis is calculated on a
10 span-by-span basis, considering: span length, weight span, catenaries in
11 each span, insulator swing, insulator weight and stiffness, all to analyze
12 the line under very high temperature (VHT) conditions without the
13 errors introduced by the standard Ruling Span concept.

14 In this process, the catenary shapes of the wire in each span
15 must be accurately determined for various conductor conditions, such as
16 maximum desired temperature, and wind and ice loadings of the line
17 under normal conditions. This is done through multiple iterations of
18 the calculations in the longitudinal loading model.

19 From such analysis, clearance violations are identified on an
20 individual span by span basis. This is generally done with a
21 commercially available power line analysis spotting optimization program,
22 such as TLCADD, taking into account the movement of insulator strings
23 and individual structure stiffness.
24

Also as part of this process (Fig. 1:6), the critical spans (spans with clearance violations) created by higher conductor operating temperatures are noted. The nature and severity of each clearance violation is noted.

a) This invention considers two methods for eliminating the clearance violation in the critical spans, which methods have not previously been used for this purpose. Each of these methods are considered and the resultant line characteristics, on a span-by-span basis, are determined; again, through multiple iterations of the longitudinal loading model. While hand calculations are possible, use of a computer program or other automated procedure will greatly assist the designer with these multiple iteration calculations. It is necessary to analyze each span separately, considering a virtually infinite number of combinations of how much and where to either cut out pieces of the conductor, or to slide the clamps, or some combination of both, over a several span section of the system.

b) Each span must be separately analyzed in order to overcome the errors inherent in the commonly used "Ruling Span" concept. With a change in the length of the wire, there is a corresponding change in the wire tension. To achieve equilibrium at the conductor support points at either end of the span, the insulators and, to a lesser degree, the structures, move to balance the forces in the adjacent spans. The formulae for calculating the change in the length of the wire and the corresponding change in tension are commonly available within the

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1 industry; see, for example, Southwire Company, Overhead Conductor
2 Manual, First Edition, 1994.

3 c) The movement of the insulators is determined by resolving the
4 forces in a static equilibrium calculation. Since the movement of each
5 insulator is affected by the adjacent spans, mathematically determining
6 the equilibrium points of a multi-span wire system requires multiple
7 calculations in an iterative process. Wire systems larger than two to
8 four spans may require hundreds of calculations in multiple iterations.
9 The availability of commercially available computer programs, such as
10 "SagSec" (by PLS) or "Nip & Tuck" (by ECSI), will speed the
11 calculation process to the point of practicality.

12 d) Removing a small piece of the conductor increases the tension,
13 which will cause the insulators to move so that equilibrium at the
14 insulator is maintained. Since this insulator movement affects the
15 tension in the adjacent spans, an iterative solution is required to find
16 what the equilibrium point is for each of the affected spans. A similar
17 process occurs when the position of the support clamps is changed. By
18 doing so, the length of wire in two spans are changed, which changes
19 the tension in at least three spans, which will cause the insulators on
20 each end of the spans affected to move to new equilibrium positions.
21 Again, for a multi-span line section, this will require multiple iterations.

22
23 In performing these analyses, the designer considers:

- 24 1. the initial position of the insulators and conductor;

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2. the change in tension in the conductor at each span;
3. the position on the conductor where the support clamps should be reattached;
4. vibration limits on the line and structures (Fig. 1:8);
5. maximum tension capabilities of all components (Fig. 1:8);
6. flexibility of the structures;
7. insulator swing at each structure (Fig. 1:8);
8. resultant load applied to each structure (Fig. 1:8); and
9. the resultant actual catenaries at various temperature and conductor loadings (Fig. 1:7)

The designer will need to use best practice as judgment to determine the true practical feasibility of the recommendations from the first analysis, for removal of pieces of the conductor and movement of clamps at various structure locations, and develop an optimal solution.

A display of the results might look like Figure 2. In this example, the "Trial B" section indicates a need to remove 1.75 feet between 29 and 30 (Fig. 2:1) and a removal of 2.25 feet between structures 22 and 23 (Fig. 2:2). Trial B also recommends a movement of the clamp at structure 30 backwards by .25 feet (Fig. 2:3), and movement of the clamps at structure 29 ahead .25 feet (Fig. 2:4), as well as a backwards movement of the clamp at structure 23 by .25 feet (Fig. 2:5).

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1 "Trial B" is used to verify the sag clearances and insulator
2 deflections at the preferred very high temperature (VHT) operation
3 assuming the corrections introduced, as reflected in the Trial B columns
4 marked "Removal" (Fig 2:6) and "Shift" (Fig. 2:7). As there are
5 potentially an unlimited number of different options regarding the
6 application of the procedures, this "Trial B," may be repeated several
7 times to optimize the cost and find feasible solutions on a difficult
8 section of line. The optimization is usually focused on minimizing the
9 number of field operations, that is minimizing the number of pieces of
10 the conductor to remove and the number of clamp movements. Such
11 things as insulator deflection, longitudinal loading, conductor vibration,
12 uplift, construction access, construct-ability, and energized versus de-
13 energized must also be considered and evaluated by the engineer (Fig.
14 1:8).

15 The cost of these procedures, used separately or in conjunction
16 with each other, is calculated and compared to the costs for the
17 standard alternatives (Fig. 1:9).

18 Using standard engineering procedures, construction estimates are
19 prepared for various standard design modification alternatives (Fig. 1:9).
20 The engineer should include such other standard modification possibilities
21 as:

- 22 1. Putting in all new conductor with more power
23 transmission ability; including replacement of components not
24 currently capable of bearing the additional stresses imposed by

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new conductor. These components may include poles/towers, crossarms, braces, bolts, insulators and other structural components;

2. Increasing the height of some structures;
3. Increasing the number of structures;
4. Re-sagging: putting the whole line or line segment, from dead end to dead end, in sheaves, pulling it tighter at a fixed location, allowing the line to seek its own sag 'level', then re-clamping; and
5. Attempting to do some or all of the field modifications with the power line energized.

In the event the costs of all alternatives are higher than allowable, a recommendation of a lower operating temperature, with calculations made of how much the line could be altered, under the lowest cost alternative, and a determination is made of how much the operating temperature of the conductor could be increased given that level of alteration (Fig. 1:9).

Figure 3 is an example of a graphic output from a commercially available computerized longitudinal loading analysis program showing, in this case, two structures (Fig. 3:7), their station numbers or distance along the line (Fig. 3:6), the sag in the conductor at normal maximum operating temperature and conditions (Fig. 3:8), the expected sag in the line if operated at maximum desired temperature without modification

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(Fig. 3:9), and the sag in the line at the higher operating temperature desired and after the determined optimal modification (Fig. 3:10). This is the image that would be used as the final overlay in comparison (Fig. 1:13).

Once a preferred field modification plan is determined, and client approval obtained (Fig. 1:14), then construction drawings and specifications are prepared (Fig. 1:11). A report is prepared for the construction forces (Fig. 1:10). This describes, in order, precisely where and how much conductor to remove and which clamps to move, how far and which direction.

The power line conductor(s) is then physically altered by making the cuts and resetting the clamps as prescribed by the process. The actual field modifications to the conductor are an integral part of the invention as the construction process is only possible with the invention's detailed construction specifications (Fig. 1:12). Standard construction techniques would be used for the actual cutting and splicing of the conductors, and the loosening, sliding and tightening of clamps.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or

1 modifications within the proper scope of the appended claims
2 appropriately interpreted in accordance with the doctrine of equivalents.
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